Remote-Sensing Data in Estimating Inputs to Ecosystem Models

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To better understand carbon cycling in forest ecosystems, several process-based ecosystem models have been developed. The forest leaf-area index (LAI) and other variables describing plant biomass are necessary to run these models. The only feasible means of estimating these forest variables for spatial extents of tens of meters and larger depend on remote-sensing instruments. In the past, reflectance index measurements based on optical remote-sensing data have been used to estimate LAI. This work involves developing algorithms for combining remote-sensing data in the microwave and optical regions of the electromagnetic spectrum (1) to increase the accuracy of LAI estimates, as well as the estimates of other variables; and (2) to extend the range of validity of LAI estimates beyond that achieved from optical data alone.

The first step was to assemble data from the Boreal Ecosystem-Atmosphere Study campaigns. Airborne synthetic aperture radar and Landsat Thematic Mapper images obtained for the Southern Study Area (SSA) were calibrated to physical units and georectified. Statistical relationships between the image and ground measurements were examined for 15 plots within the SSA along with the general covariance between the optical and radar data. The second step was to determine if the radar data detect and provide additional information or augment the optical measurements. This work is one of the few efforts to combine the diverse technologies of passive and active remote sensing for the purpose of answering ecological questions. Mahta Moghaddam of the Jet Propulsion Laboratory in Pasadena was a co-investigator on this project.

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Paleoenvironmental Studies

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A revision of a pollen profile was undertaken in order to start astrobiological research in South America. Gruta del Indio del Rincón del Atuel (GIRA) is a rock shelter located at lat. 34° 45′ S and long. 68° 22′ W, east of the Andes. The stratigraphy of GIRA includes fossil traces of archeological, paleontological, and paleoecological events. Previous research in this important site showed three groups of ecological indicators: (1) plants of the Monte ecosystem that depend on the groundwater table (phreatophytes), (2) Monte ecosystem plants that are independent of the groundwater (nonphreatophytes), and (3) plants of the Patagonia ecosystem. These groups of indicators were used to piece together plant succession in this area in a time frame of more than 32,000 years before present (BP). Such history includes a first occupation by the Patagonia ecosystem during the last 20,000 years, corresponding to the last Ice Age, then a Monte occupation from 10,000 years to the present. The latter is subdivided into a phase of phreatophytic dominance that ends about 2500 years BP and a nonphreatophytic dominance that persists through the present. This time, a thorough analysis of its paleoenvironmental content was performed in looking for indicators of declining ecosystems. The first figure shows the results of such analysis.

The paleoenvironmental record was divided into three major zones. Zone I (from 32,000 years to about 10,000 years ago) is characterized by indicators of the Patagonian ecosystem, suggesting climate controlled by the Pacific high pressure cell, with 200 millimeters of annual precipitation (mostly in winter), and a mean annual temperature of 8°C. Zone II (from 10,000 to about 3000 years ago) is characterized by indicators of riparian environments

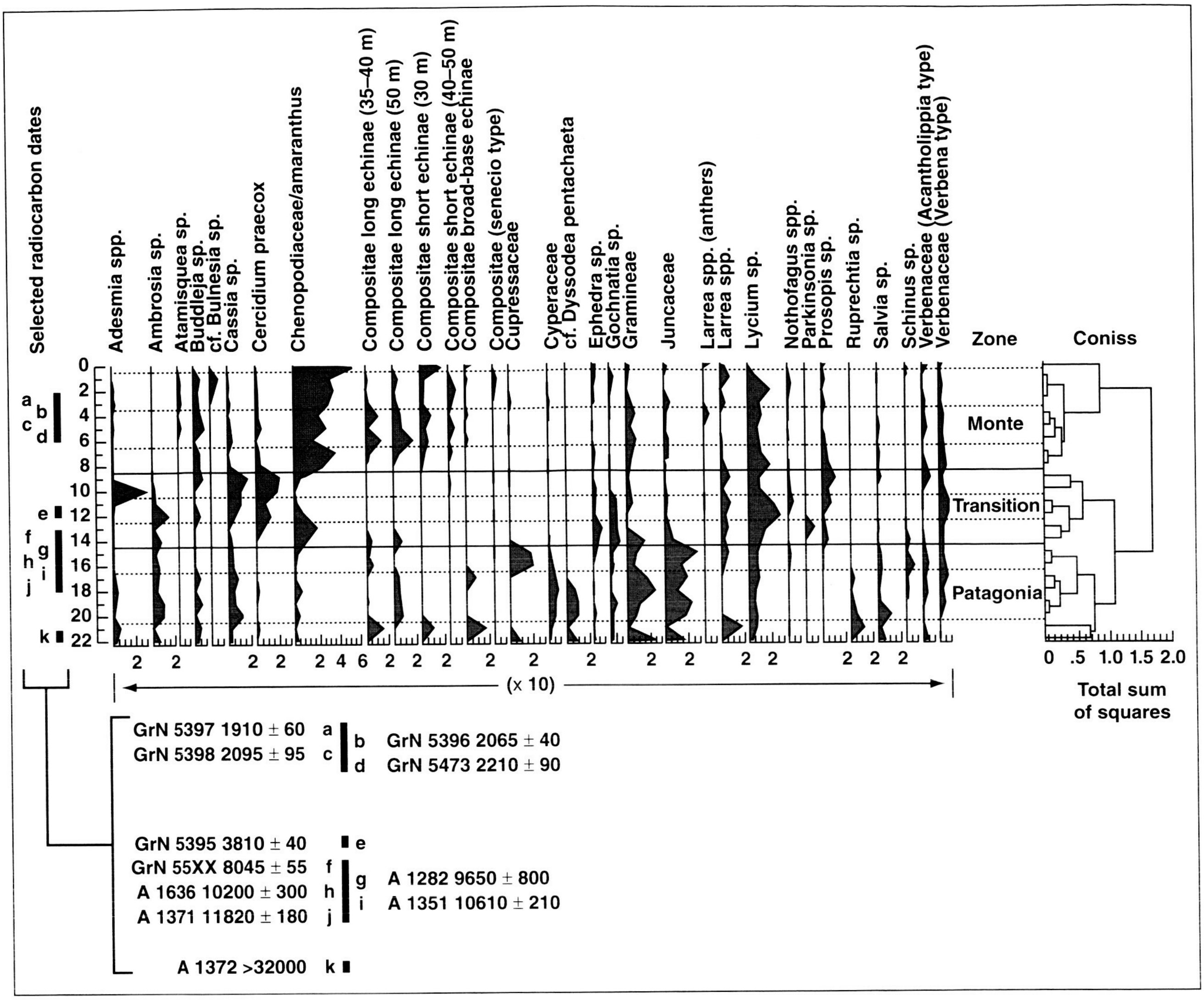

Fig. 1. The Gruta del Indio Profile pollen profile. Depth corresponding to age before present is shown on the y-axis.

in the desert such as *Prosopis julliflora* (algarrobo, mezquite), small trees like *Cercidium praecox* (brea, palo verde), and a high frequency of *Lycium* sp., a woody Solanaceae, and *Cassia* sp., a bush of the Leguminosae. These indicators suggest more precipitation and higher temperature. GIRA is not far from the Atuel River, which originates in the Andes and, at the time of transition from glacial to postglacial time, may have had a much larger flow volume than at the present, thus enlarging the area of riparian environments. Increased precipitation and higher temperatures may be linked to a stronger influence of the Atlantic high pressure cell in this region. Zone III (from 3000 years ago to the present) is characterized by dominance of annuals (Chenopodiaceae plus *Amaranthus* sp. and several types of Compositae). *Lycium* sp. is an important indicator. This zone reflects Monte plant geographic province conditions (similar to those of the Sonoran Desert in the Northern Hemisphere), with 300 millimeters of annual precipitation, most of which occurs in summer, and a mean annual temperature of 14°C. This profile shows that climate change between Pleistocene and Holocene times triggered changes in ecosystems such that, by about 10,000 years ago, the Patagonian ecosystem declined locally, giving place to a relatively fast succession of dominant taxa in Zone II (Transition) leading to Zone III (Monte) with a deep reorganization that preserved some indicators of the previous ecosystem (i.e., *Lycium* sp.), and passed dominance to annual herbs (Chenopodiaceae + *Amaranus*) and several types of Compositae. Some indicator genera are absent in the new ecosystem: *Adesmia, Ambrosia*, Cupressacea, *Cyperaceae, Dyssodea, Parkinsonia, Ruprechtia*, and *Salvia*.

Indicators replaced in the past from one ecosystem to the next may be provisionally assigned to either competition or genetic limitations. When environmental conditions change, several plant groups are pushed to local extinction because their minimum environmental needs are no longer met. GIRA's record makes a good case for local extinction of *Ruprechtia, Schinus*, some Juncaceae, Cupressaceae, Cyperaceae, some Compositae, and *Adesmia* sp. at the onset or at the end of the Transition zone. At the same time, other indicators are established during the Transition time, *Cercidium, Prosopis, Parkinsonia, Ephedra ochreata*, some Compositae, and others. In order to identify indicators of a process of ecosystem decline, more research is needed in ecosystems as well as in population ecology in order to obtain mechanistic explanations for displacement or extinction. An additional, very valuable indicator in GIRA's record is *Mylodon listai*, the giant sloth that left this latitude at the end of Pleistocene, migrated south, and became extinct at mid-Holocene time.

The process described above shows that the boundary between Patagonia and Monte ecosystems moved northward during the Ice Age and toward the south in the postglacial time. Locally, about 9000 years ago such displacement resulted in the extinction of most of the Patagonia ecosystem and the giant sloth. Intensive research of both local disappearance and extinction of ecosystem components will provide further insight into the astrobiology question of rapid environmental changes and their consequences on ecosystem properties.

Data analysis of the Oregon Pollen Transect is finished and the results are shown in the second figure. Cluster analysis of samples ordered along the Dayville-Newport + Cascade Head transect resolved

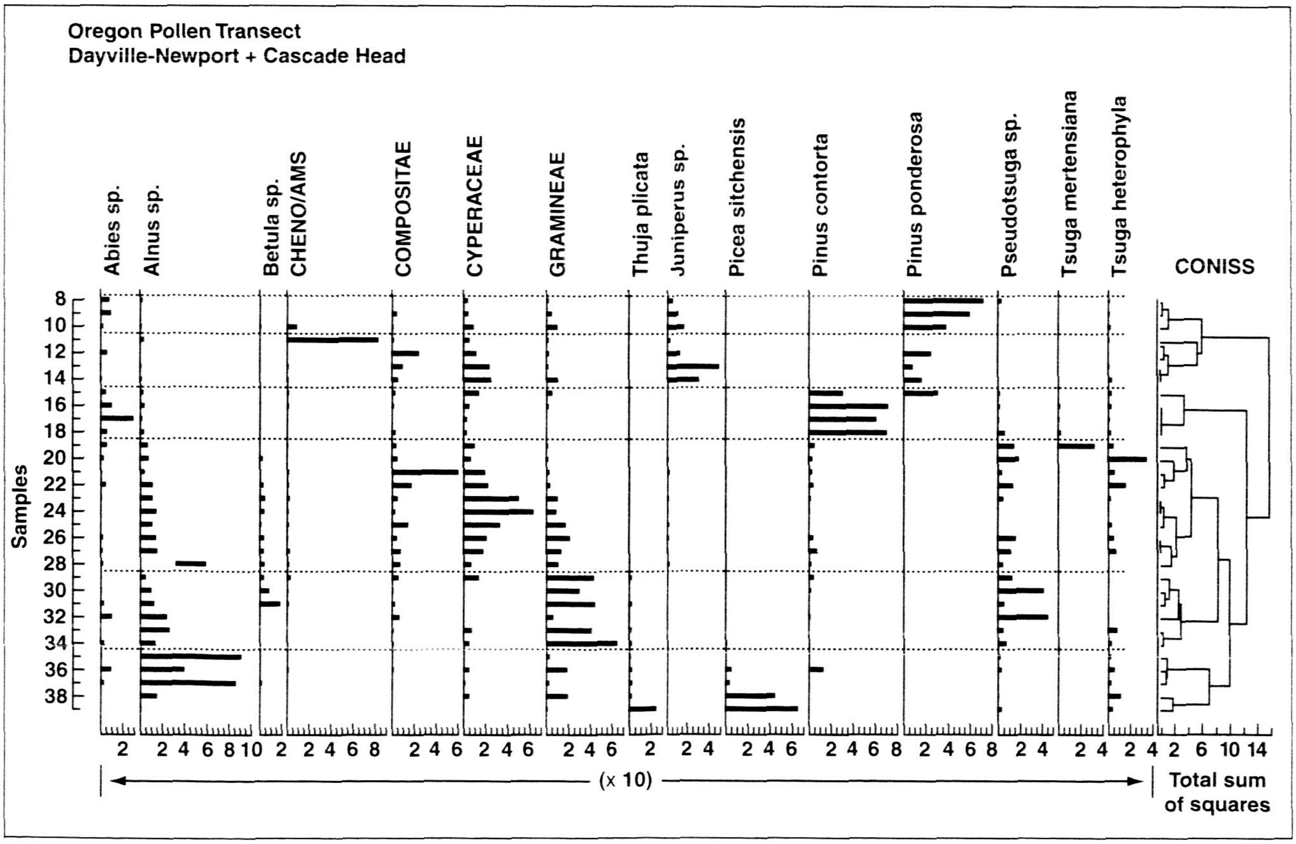

Fig. 2. Oregon Pollen Transect pollen profile.

vegetation zones quite clearly. Thus, samples 8–10 correspond to the Ponderosa pine (*Pinus ponderosa*) zone; samples 11–14 correspond to the Western juniper (*Juniperus occidentalis*) zone; samples 15–18 correspond to the Grand fir (*Abies grandis*) zone east of the Cascades; samples 19–28 correspond to the Pacific silver fir (*Abies amabilis*) zone above an elevation of 1000 meters and the Western Hemlock (*Tsuga heterophylla*) zone west of the Cascades; samples 29–34 correspond to the Willamette Forest and Prairie zones; and samples 35–39 correspond to the Sitka spruce (*Picea sitchensis*) zone. This high correspondence of pollen and vegetation illustrates that pollen is a strong predictor of vegetation. Using results from the OTTER Project (Oregon Transect Ecosystem Research Project), and assuming a linear relation between pollen variables and vegetation indices, a model was produced; the improved model can be used to reconstruct past environments in order to create vegetation indices from fossil pollen data (i.e., "hindcasting").

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Global Land Surface Monitoring with Low-Resolution Satellite Imagery

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The only practical way to produce maps of large regions of the globe is to use remotely sensed data that have coarse spatial resolution, such as data from the advanced very-high-resolution radiometer (AVHRR) at 1.1-kilometer resolution, or the soon-to-be launched moderate-resolution imaging spectroradiometer (MODIS) instrument at resolutions of 250 meters to 1 kilometer (MODIS is a "moderate-resolution" instrument by today's standards). However, the accuracy of the resultant maps is in doubt, especially for mapping highly fragmented land-cover types such as burn scars in forests and grasslands and ponds in Arctic tundra. These land-cover types are important in climatology, hydrology, and other Earth sciences. The objective of this project is to develop an approach for improving area estimates by modeling the distribution of patch sizes of homogeneous land cover, such as open water or the ash layer left by fire.

Digital maps of fire scars in Brazil from both the Landsat multispectral scanner imagery (56-meter resolution) and AVHRR imagery and of water bodies in Alaskan tundra from the Earth Resources Satellite ERS-1 synthetic aperture radar imagery (at resolutions of 12.5 and 100 meters) have been developed. Statistical analysis has confirmed the important contribution of small patches to the overall extent of these land-cover types and has identified candidate models, exponential or power curves, for the fine-scale distributions. Comparison of Landsat and AVHRR maps revealed the types of pixelation effects, caused by low spatial resolution, that can cause errors in area measurements. Software to simulate patch-size distributions at various resolutions has been created and will be used to investigate the relationships between size distributions observed at different resolutions and to develop a new procedure for improving area estimates. Gerry Livingston, School of Natural Resources, University of Vermont, was a co-investigator on this project.

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